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VECTOR ELECTROCARDIOGRAPHY

Vector electrocardiography is based upon a fact and an assumption regarding the electrocardiogram (ECG): the fact is that the ECG deflection is an extremely accurate measurement of the electrical forces generated by the heart; the assumption, which the physics of the electrical field of the heart generally affirms, is that, in effect, there is a single electrical force for each instant during the heart cycle and all body surface leads record from the same instantaneous electrical force. The deflections are different on the various leads simply because they measure the force from different locations or points of vantage on the body. These two principles make it possible to measure the electrical forces of the heart from the body surface leads, and the ECG interpretation can be based upon these measurements. Such a method of interpretation is not only more physically sound than methods based upon "patterns" but is also more objective and accurate. The following will be a necessarily brief and simplified description of vector electrocardiography.

WHAT IS VECTOR ELECTROCARDIOGRAPHY?

The electrical forces of the heart are measured by quantitatively expressing their magnitudes and directions. The mathematical symbol used for this is the "vector" which resembles an arrow, its length indicating the magnitude of the force and its inclination in space indicating the direction of the force. Accordingly, the electrical forces of the heart responsible for P, QRS, and T waves can be represented by P, QRS, and T vectors.

When a vector is generated by the heart, the size of the deflection it writes on a lead is a measurement of that component of the vector which is parallel with the lead axis (the imaginary line connecting the two electrodes of the lead). A simple way to look at this is to consider the component of the vector as the "shadow" cast on the lead axis by the vector when there is a light source facing the lead (fig. 1). When the component points toward the positive electrode, an upright deflection is written, and, when it points toward the negative electrode, a downward deflection is written. These are the principles of "projection," and they are basic in vector electrocardiography.

Fig. 2 illustrates how these principles are used to measure the magnitude and direction of a vector in space. Two leads are selected, XX^1 and YY^1; they define one plane in the body. A graph is drawn showing the directions of the two lead axes in this plane. The amplitudes (more accurately, the net enclosed areas) of the deflections on the two leads are plotted on the axes of the graph with due regard for the polarity of the leads. These plots indicate the magnitudes of the components or "shadows" of the vector on each of the lead axes. Then, to define the vector, perpendiculars are dropped from the components, and the point of intersection of the perpendiculars defines the terminus of the vector in that plane. Of course, this vector is itself only the projection or "shadow" cast on this plane by the

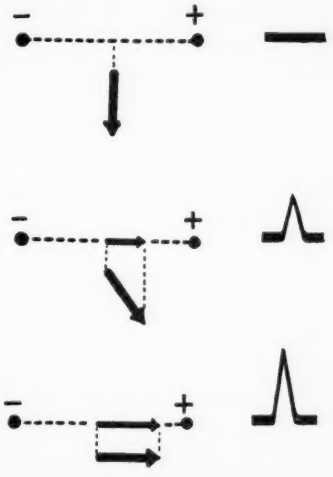

Fig. 1

spatial vector. Therefore, a third lead, ZZ^1, is selected whose axis lies in another plane. The amplitude of the deflection on this lead measures the projection of the vector on a lead axis in this second plane. From the measurements in the two planes the spatial vector can be drawn. At present two methods are used to present spatial vectors: the more graphic method is to draw the

vectors three-dimensionally as in the figure; a more accurate method is to show the projections of the vector on two or more planes.

As the QRS process spreads over the heart, it generates myriads of QRS vectors from each region. The resultant of all vectors generated at a given instant is called the "instantaneous spatial QRS vector," and it is this vector which the ECG deflection measures. Because different regions of the heart undergo activation from instant to instant during the QRS interval, the

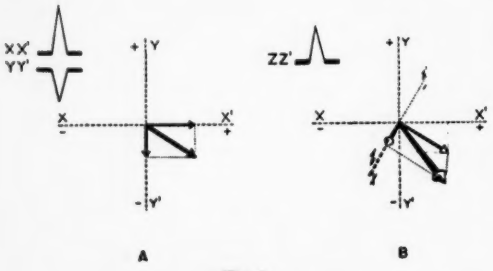

Fig. 2

instantaneous QRS vectors are different in magnitude and direction during a single QRS cycle. One can describe their sequence of change by plotting all the instantaneous vectors for the QRS cycle on a single graph and drawing a line through their termini (fig. 3). This line is called the "QRS loop" or "QRS vectorcardiogram (VCG)." The average of all instantaneous vectors in the QRS interval is called the "mean spatial QRS vector." Mean vectors and loops can also be constructed from P, ST, T, and U waves, using these same principles. A relatively simple method for calculating mean spatial vectors and spatial loops from conventional ECG deflections and the clinical application of this type of information have been described.[1]

OSCILLOSCOPIC VECTORCARDIOGRAPHY

Interest in vector electrocardiography has been greatly stimulated by the introduction of the cathode ray oscilloscope for recording electrical forces. The reason for this interest is that, whereas the conventional ECG records the projections of the spatial vectors on only a single lead axis in a given tracing, the oscilloscope can record projections of the vectors on two lead axes simultaneously. The beam of electrons forms a point of light on the surface of the tube, and with every heart cycle this point of light traces out the P, QRS, and T loops as projected on the plane of the body defined by the two leads. In doing this, it follows the same principles of projection illustrated in fig. 2. Then, by selecting two leads in another plane of the body and recording the loops in this plane, the spatial vectors and spatial loops can be determined from just two records. Such oscilloscopic loops are much more accurate and detailed than loops constructed from conventional ECG deflections. The term "vectorcardiography" has come to refer principally to these oscilloscopic loops.

In order to measure the resultant vectors of the heart, either with an oscilloscope or from conventional ECG deflections, the electrodes for the various leads must be equidistant from all vectors generated by the heart and must be equidistant from each other. Einthoven, who recognized this requirement, concluded that one way to achieve it would be to place the electrodes as far away from the heart as possible. With this purpose in mind, he introduced the three limb leads. The reference figure formed by these leads is now generally accepted as satisfactory for measuring the projections of the vectors in the plane defined by these leads, the frontal plane of the body. For oscilloscopic purposes, any two of the various unipolar and bipolar leads may be used, with proper circuits, to record frontal plane loops.

Measuring the anterior-posterior components of the spatial vectors has been a more difficult problem. Conventional precordial electrode locations are so much nearer the heart than the limb lead electrodes that they cannot be used in the same reference figure. To be sure, it is possible to determine the directions of the mean spatial vectors and to plot qualitatively accurate loops from conventional limb and precordial lead deflections, as has been described elsewhere,[1] but the magnitudes of the vectors cannot be accurately established by this method.

In oscilloscopic vectorcardiography a single anterior-posterior lead may be combined with an appropriate frontal plane lead to record the loop projections on an anterior-posterior plane. A number of different lead systems have been suggested for the oscilloscopic VCG, nearly all using relatively remote electrodes to define the various spatial planes on which loop projections are recorded.[2,3,4,5] Which system is the most "accurate" is not settled; the loops have different contours for each lead system because of differences in electrode locations and circuits, but the differences are often not great. Since all loops are artificial resolutions of the electrical activity of the heart resolving their activity into a series of instantaneous resultant vectors which in themselves have no existence in the heart,

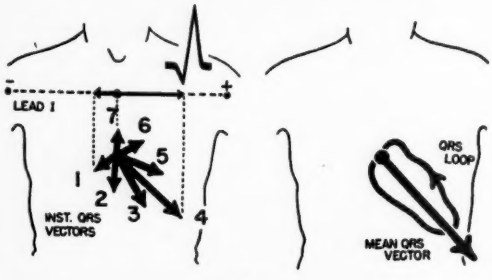

Fig. 3

there is no such thing as the "true" loop. Accordingly, several different lead systems may all give "correct" loops, depending upon the information sought. For example, loops constructed from the conventional precordial V-leads tend to "emphasize" the contributions of the left ventricle, which emphasis under certain conditions may be a more desirable type of information. In short, at

the present time, the "best" VCG lead system is probably the one which is the least complicated to perform and the most easily standardized in application.

THE APPLICATIONS AND LIMITATIONS OF OSCILLOSCOPIC VECTORCARDIOGRAPHY

Most of the research in this field has been in the study of lead systems and in instrumentation; the clinical potentialities of this technique are still largely unexplored. So far the clinical reports have been principally concerned with descriptive studies of the contour of the QRS loop in various ECG syndromes.[2, 3, 4, 5] One consequence of these studies has been the suggestion that the QRS loop may have a "diagnostic contour" on one or another plane of the body in certain ECG syndromes. Although this may occasionally be true, the projection of the loop on only a single plane is an incomplete study of the spatial vectors. Slight changes in the direction of the loop spatially can produce a marked change in the contour of its projection or "shadow" on a single plane. Furthermore, this approach tends to revive a practice that retarded conventional ECG for so many years, the memorizing of "patterns," and loses sight of the quantitative information contained in the loop.

The practical shortcomings of vectorcardiography are that the instrument is expensive and requires highly trained personnel. Also, as ordinarily operated, it produces a stationary record, and rhythm disturbances cannot be recognized. Finally, the mean vectors and the QRS-T angles, which in routine clinical practice are often a more useful type of vector information than the QRS loop, are not immediately evident in the oscilloscopic VCG. However, these are technical shortcomings and will undoubtedly be overcome with future developments in instrumentation.

The most serious shortcomings from a clinical point of view is that, when the oscilloscopic VCG is recorded from remote electrodes, it does not always contain all the diagnostically important information contained in conventional precordial leads. There are two reasons for this:

(1) The oscilloscope loop records from the instantaneous vectors as if they all arose from the same point-source within the heart. However, when an electrode lies as near the center of the electrical field as the precordial electrodes, slight changes in the distance between the electrode and the center of the field produce significant changes in the amplitude of the deflection. The reason for this is that the electrical field intensity increases algebraically as an electrode comes to lie nearer and nearer its center, and therefore at each nearer position the "scale" of measurement by the electrode is algebraically increased. There is reason to believe that the effective origin of the instantaneous vectors shifts from the anterior to the posterior regions of the heart during the QRS cycle, and this shift influences the contour of precordial QRS deflections. It does not ordinarily interfere with the use of precordial lead deflections for calculating mean vectors; however, it does cause the loops constructed from these leads to differ from those recorded oscilloscopically with remote electrodes. At present it is extremly difficult to detect and study this shift with conventional ECG methods. Perhaps with further developments in oscilloscope instrumentation it will be possible to record the actual pathway of the shift of origin of instantaneous vectors, which may indeed prove to be of clinical diagnostic importance.

(2) If there should be a very small region of the heart where the electrical events have been altered, the electrical abnormality might be too small to affect the characteristics of the resultant instantaneous vector, and the oscilloscopic VCG would not record it. However, if a precordial electrode should lie immediately above this region, the proximity of the electrode to this region would tend to "magnify" the local vector effect, and the resultant deflection would be abnormal. This has been suggested as the explanation of the "isolated T-negativity" syndrome[6] and undoubtedly also occurs for QRS forces in rare instances of myocardial infarction when the infarcted site is small in its electrical effect, producing a relatively normal oscilloscopic VCG but abnormal precordial QRS deflections.

CONCLUSION

The problems of oscilloscopic vectorcardiography have been emphasized in this review because of the great interest in this new technique. However, this is but a single technique in vector electrocardiography and unquestionably will be the stimulus for many new applications of vector methods and oscilloscopic techniques in clinical electrocardiography. It is well to remember that vector electrocardiography is not a technique or a body of facts but a concept. It represents a more rational approach than has been available heretofore for the study of an extremely complicated phenomenon and already has added substantially to the breadth and precision of clinical electrocardiography.

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(Turn Page For Announcements)

NEW ADDRESS FOR AMERICAN HEART ASSOCIATION

On and after September 20, 1952, the office of the American Heart Association will be located at the following address: 44 East 23rd Street, New York City 10, New York. Phone: GRamercy 7-9170.

AMERICAN HEART ASSOCIATION RESEARCH GRANTS-IN-AID

Applications for American Heart Association Research Grants-in-aid for the fiscal year 1953-1954 must be postmarked not later than December 1, 1952. Information and application forms may be obtained from the Medical Director.

SUBSCRIPTION RATES FOR *CIRCULATION-RESEARCH*

Subscription rates for the bimonthly journal, *CIRCULATION-RESEARCH*, the first issue of which will appear in January 1953, have been set below publication cost to encourage the widest possible readership. The Association will assume the difference as part of its professional education program. *Research Journal Membership-Subscriptions*, available through the Association and most of its affiliates, include the monthly bulletin, *Modern Concepts of Cardiovascular Disease*, and admission to the Association's annual Scientific Sessions.

The annual rates are as follows:

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ANNUAL MEETING AND SCIENTIFIC SESSIONS

The Twenty-Ninth Annual Meeting and the Twenty-Sixth Scientific Sessions of the American Heart Association will be held at the *Hotel Chelsea* in Atlantic City, N. J., *April 8-12, 1953*, immediately preceding the annual meeting of the American College of Physicians. All those desiring to attend should make room reservations at the earliest possible date. (The Hotel Chelsea is located on the Boardwalk at Morris Avenue, 5 short blocks *south* of the Convention Hall.) The Scientific Sessions will be held on Thursday, Friday, Saturday and Sunday, April 9, 10, 11 and 12.

PAPERS FOR THE SCIENTIFIC SESSIONS

All those desiring to present papers at the Association's Scientific Sessions should submit abstracts *in triplicate* of the proposed presentation to Dr. Andre Cournand, Chairman of the Program Committee, c/o American Heart Association, 44 East 23rd Street, New York 10, N. Y., not later than *January 1, 1953*. Abstracts should not be longer than 300 words and must contain in summary form, a specific statement of the results obtained or conclusions reached (not merely a statement that results or conclusions will be presented, or discussed at the meeting.)